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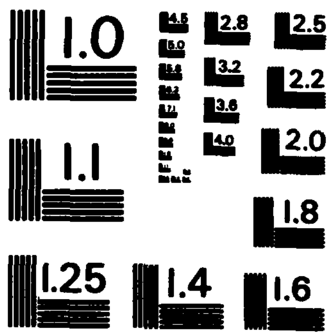

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PROGRAMMING A MULTIPLE-ORIFICE HYDRAULIC DECELERATOR

CARL G. TOLER

JUNE 1985

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FOR THE COMMANDER

Henning E. von Gierke

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The AAMRL Horizontal Deceleration Facility is used to conduct experimental research for the development of design criteria for aircrew personnel protection. The hydraulic deceleration device is a water-filled cylinder. A piston mounted on the front of a deceleration sled ruptures a frangible diaphragm positioned at the opening of the cylinder and displaces the water in the cylinder through the multiple orifices. As the piston travels along the cylinder it closes off the orifices thereby decreasing the available area for the water to escape. Bernoulli's conservation-of-energy equation was applied to the physical state of fluid flow in the cylinder, allowing the orifice area to be determined as a function of the piston cross-sectional area, acceleration, velocity and weight of the sled. A computer program was developed to determine the appropriate plug orifice and location to produce desired acceleration-time profiles. The program corrects for the energy loss due to the vena-contracta of each plug. Data from several tests were used to determine a correction coefficient for other losses, such as those attributable to conduit length and surface roughness, as a lumped quantity.

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PREFACE

This report was prepared by the Biomechanical Protection Branch, Biodynamics & Bioengineering Division of the Harry G. Armstrong Aerospace Medical Research Laboratory. This report describes a hydraulic deceleration device, the physical laws governing its operation, and presents an accurate method of determining the correct orifice arrangement to produce desired acceleration-time profiles.

The author wishes to acknowledge the personnel of the Dynalectron Corporation for their support in developing the computer program to produce the desired hydraulic decelerator profile and for the electronic data used in the analysis. The author is grateful to Capt Michael P. Connors and Mr. James W. Brinkley for their technical assistance and guidance in this developmental program. Special thanks is offered to Mrs. Jeni Blake for her administrative support in the preparation of this documentation.

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INTRODUCTION

The mission of the Biomechanical Protection Branch includes development of design criteria for crew protection against transient acceleration and measurement of the interaction between the dynamic response of the human body and protection systems during acceleration. This technology is acquired for application to the design of crew safety systems such as: emergency escape systems, personnel restraint devices, and impact attenuators. One of the facilities used by the Branch to accomplish this mission is the Horizontal Deceleration Facility.

The Horizontal Deceleration Facility is an impact test facility that consists of a launch system, a two-rail track, a sled, and a hydraulic deceleration device. The facility is shown in Figure 1. The launch system is used to gradually accelerate the sled along the horizontal track. The specimen to be tested is mounted on top of the sled. After separation from the launching system, the sled is allowed to free coast along the track for 125 feet. During the free-coast phase the sled velocity may be controlled by means of braking devices mounted on the sled. The primary impact environment is produced at the end of the free-coast phase by the hydraulic deceleration device (Kilian and Brown, 1980).

The hydraulic deceleration device was designed to provide an impact acceleration-time profile which can be altered to meet the requirements of different research programs. Acceleration-time profiles are produced by the resisting force on the end of a piston mounted on the front of the sled. During the impact event the piston displaces water through the orifices arranged in a spiral pattern along the cylinder of the hydraulic deceleration device. The sizes of the orifices can be changed to control the acceleration-time profile. Changing the configuration of the hydraulic deceleration device for different acceleration profiles has proved to be time consuming and expensive due to the amount of trial and error associated with the current method of configuring the device. The same method was used to configure the Daisy Decelerator (Chandler, 1967). Several tests are usually required before the desired acceleration-time profile is obtained. Therefore, the objective of this study was to develop a more accurate and efficient means of establishing correct orifice configurations for the hydraulic deceleration device.

MATERIALS AND METHODS

FACILITY

The hydraulic deceleration device, shown in Figure 2, consists of a water-filled cylinder, a reservoir which surrounds the cylinder, and structural members to transmit forces to a reaction mass. The cylinder is constructed of a series of seven blocks, 8 inches in length. The blocks are bored to mate with a five-foot long piston that is mounted on the front of an impact sled. The piston is seven inches in diameter with 0.010 inch radial clearance in the cylinder. Each block has a series of 33 threaded 1 1/8 inch-diameter holes to receive plugs with orifice areas ranging from 0.010 to 0.994 in^2. The spacing between the centers of consecutive plugs is 0.187 inch along the longitudinal axis to create a spiral arrangement of the orifices along the cylinder. Larger transition plugs are mounted between each block with orifice areas ranging from 0.161 to 3.976 in^2.

Before each test a frangible diaphragm constructed of polyethylene film is fixed to the opening of the cylinder and the hydraulic deceleration device is filled with water. As the sled approaches the hydraulic deceleration device, the piston ruptures the diaphragm and forces the water out through the orifices. The orifices act as throttling valves restricting the flow, thereby creating a back pressure on the face of the piston. The pressure on the face of the piston decelerates the sled. Since the orifices are arranged in a spiral pattern along the cyliner, the sled acceleration can be programmed as a function of displacement along the hydraulic deceleration device.

PHYSICAL PHENOMENON

The action of the piston in the cylinder is much like a piston pump. The force applied to the piston is from the momentum of the sled. As the piston travels along the bore of the cylinder, the orifices are closed off. Thus, the orifice area available for the water to flow is continuously decreased. Figure 3 shows side and end views of the hydraulic deceleration device illustrating the arrangement of the orifice plugs with the piston partially inserted into the cylinder.

If the assumption is made that steady flow of a frictionless, incompressible fluid is occurring along a streamline, then Bernoulli's conservation-of-energy equation can be applied to describe the physical state of the fluid (Streeter, 1958).

$$z + \frac{P}{\gamma} + \frac{V^2}{2g} = C \qquad (1)$$

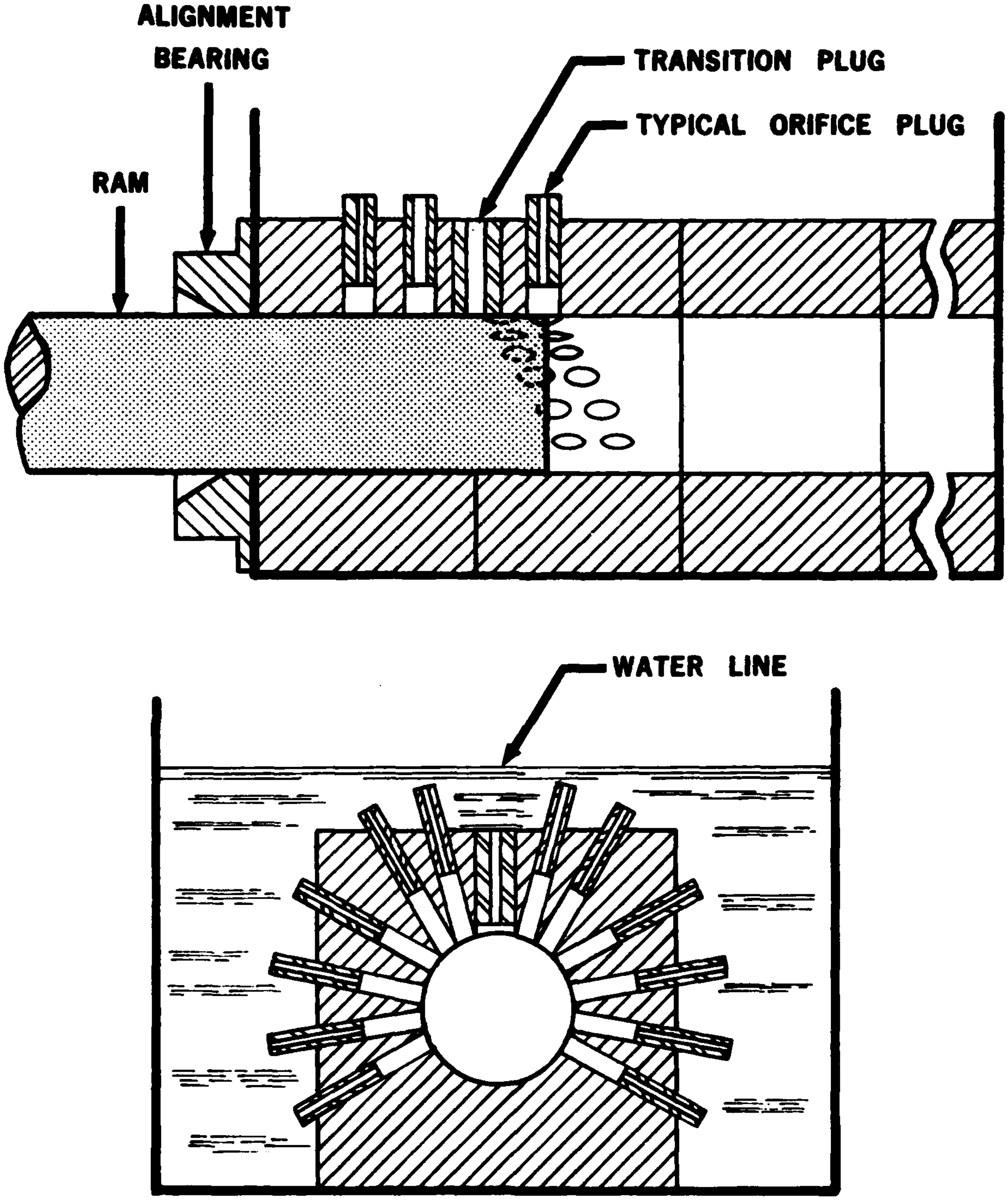


FIGURE 3. SIDE SECTIONAL VIEW AND END VIEW OF THE HYDRAULIC DECELERATION DEVICE

where A_0 is the sum of all the orifice areas not passed by the piston. Substituting equations 3 and 4 in equation 2, the equation of state is defined as:

$$\frac{W_s G_s}{A_R \gamma} + \frac{V_s^2}{2g} = \frac{V_s^2 A_R^2}{2g A_0^2} + H_L \tag{5}$$

In the analysis of fluid flow in a pipeline, several sources are present to contribute to the energy loss, H_L. One source is friction, defined as:

$$f\frac{L_e V^2}{2Dg} \tag{6}$$

where f is a dimensionless term representing the relative roughness; L_e is the equivalent length of the conduit; and D is the diameter. This loss effect is difficult to determine analytically and is best determined experimentally. This is impractical to do for all the orifices. Another source is the loss at the entrance to a pipeline from a reservoir. This applies to the entrance of each plug and usually varies between $0.05V^2/2g$ to $0.5V^2/2g$, depending on the squareness of the edge of the opening. A third source of energy loss is due to a sudden contraction in a pipeline. This occurs at the base of each plug where the opening is suddenly decreased from the diameter of the plug to the smaller diameter of the orifice in the plug. The contraction coefficient for water flow in a pipeline is known as a function of the area ratio and is presented in Table 1.

Table 1. CONTRACTION COEFFICIENT VERSUS AREA RATIO

A_2/A_1 -	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
C_c -	0.624	.632	.643	.659	.681	.712	.755	.813	.892	1.00

The energy loss due to the contraction is defined as:

$$h_c = (1/C_c - 1)^2 \frac{V_2^2}{2g} \tag{7}$$

Substituting h_c for H_L in equation 5 and rearranging terms, then Bernoulli's equation becomes:

$$\frac{A_0}{\sqrt{(1/C_c - 1)^2 + 1}} = \frac{A_R}{\sqrt{(2gW_s G_s/A_R V_s^2 + 1}} \tag{8}$$

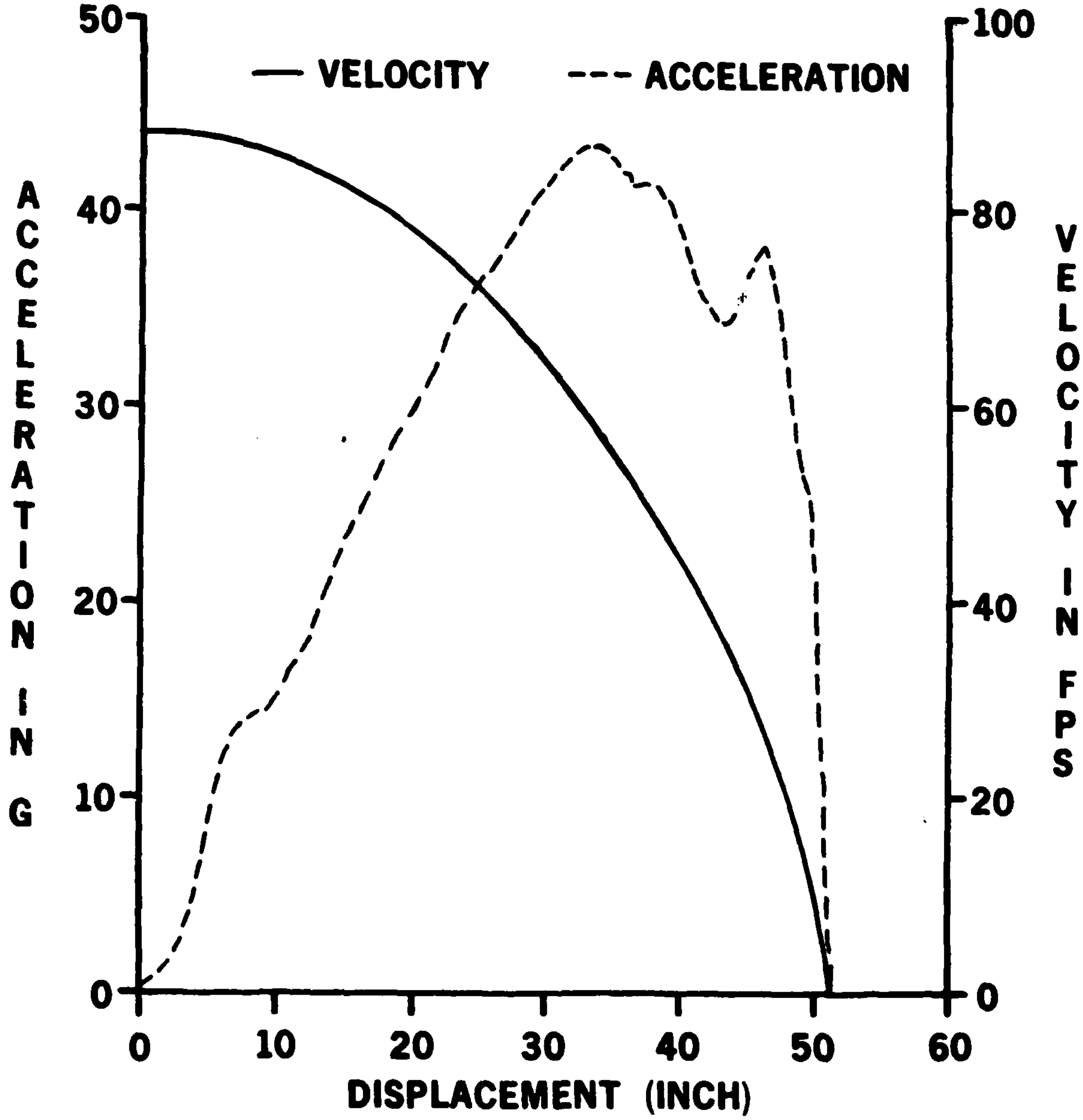


FIGURE 4. ACCELERATION AND VELOCITY VERSUS DISPLACEMENT FOR TEST 1441

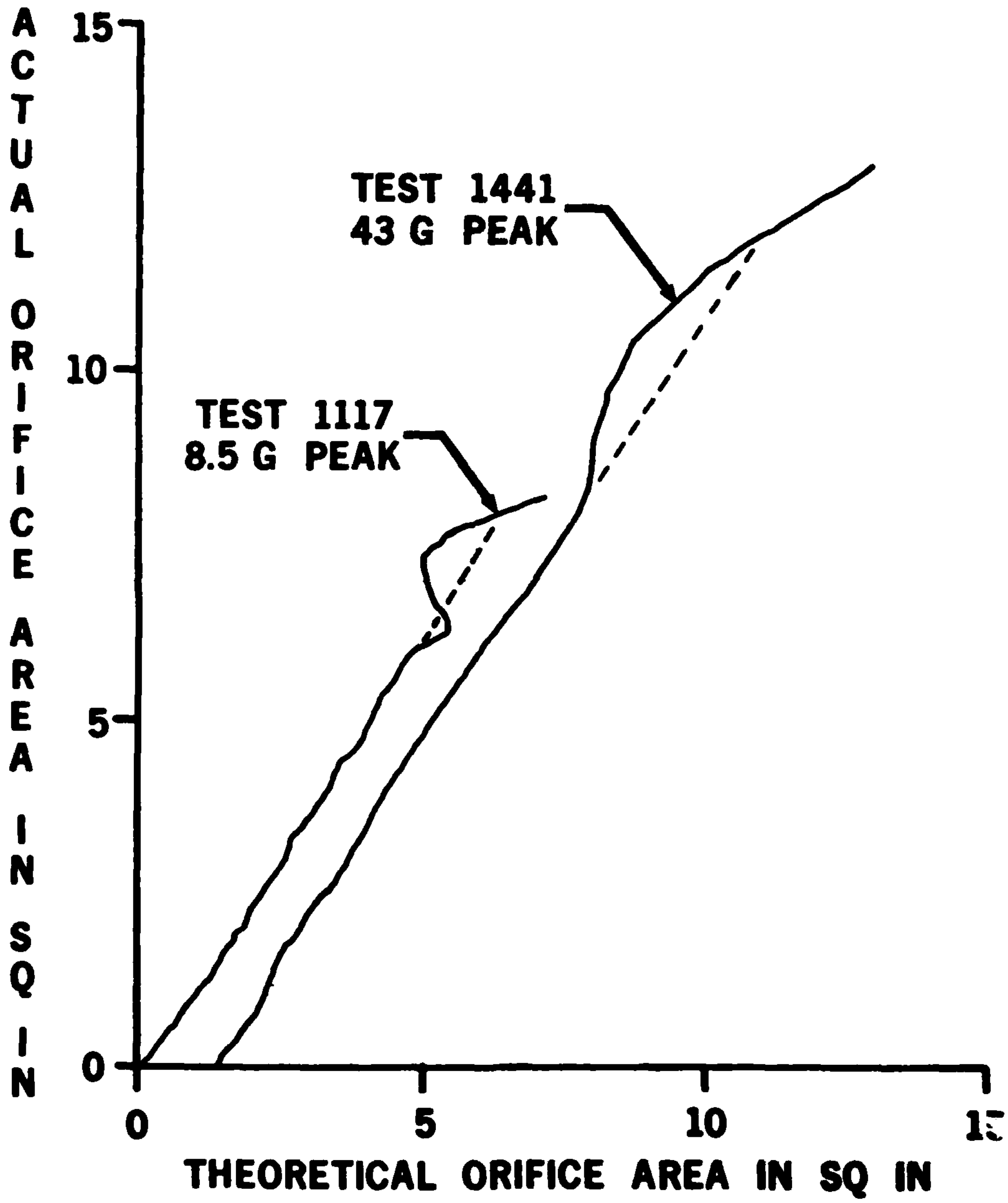
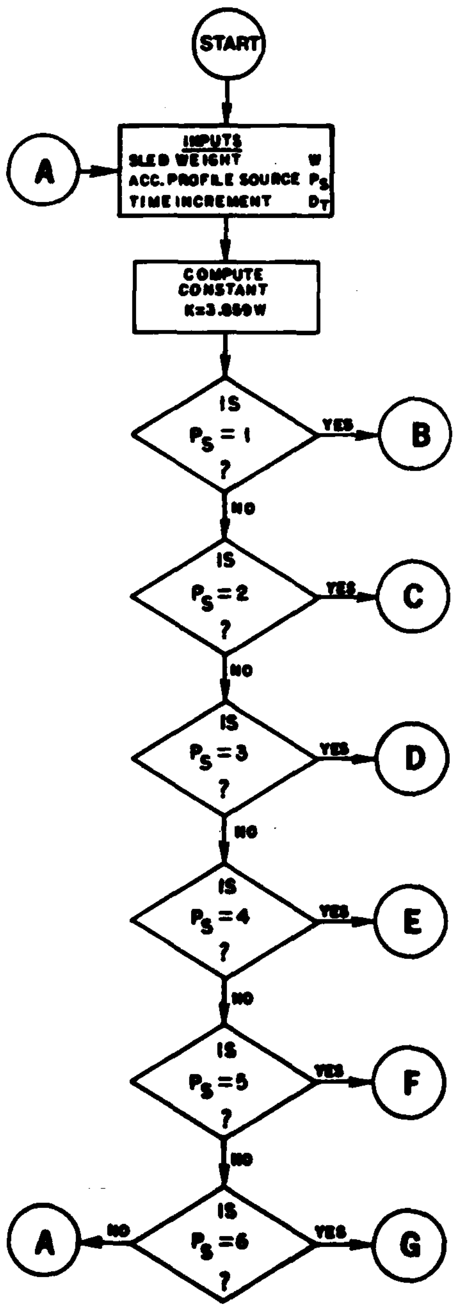


FIGURE 5. ACTUAL VS. THEORETICAL ORIFICE AREA

DISCUSSION

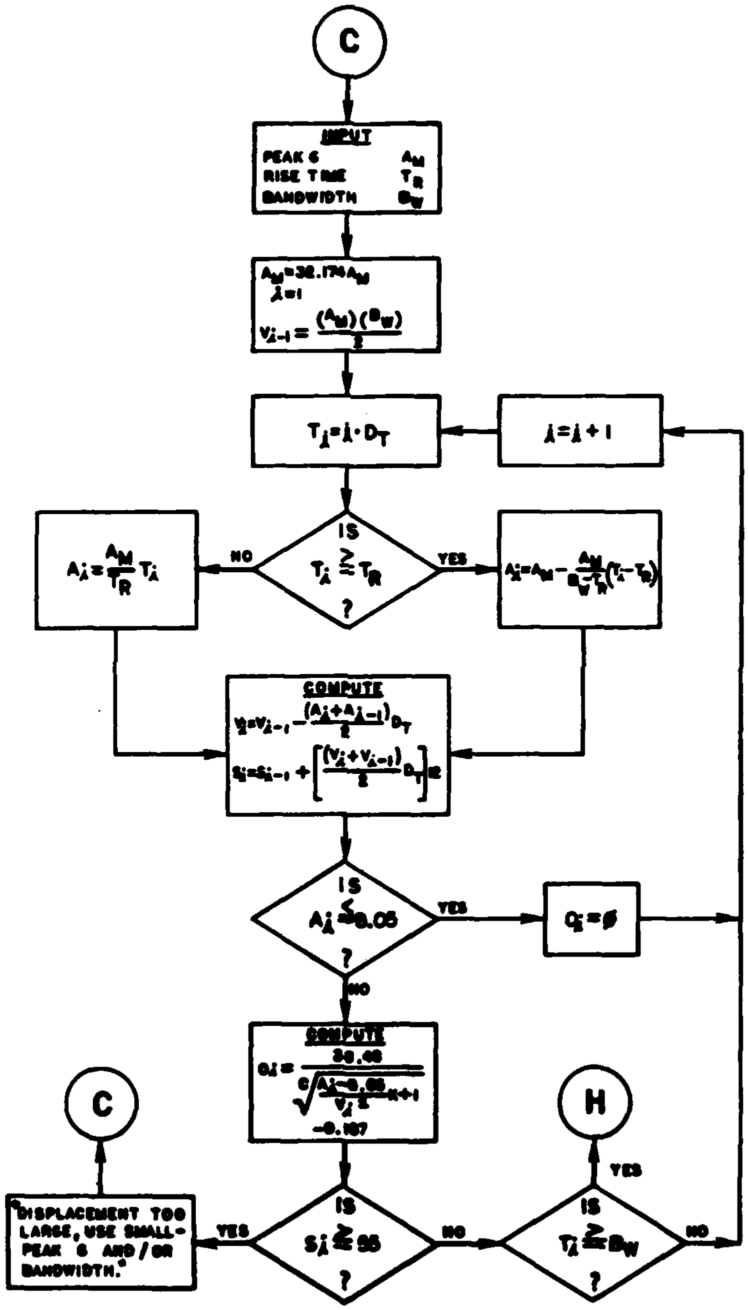
The hydraulic deceleration orifice profile can be determined by the application of Bernoulli's conservation-of-energy equation to the physical state of fluid flow during the impact event. Energy losses due to the vena-contracta of each orifice was included in the calculation of the required orifice area. Losses due to friction and square edged orifices were determined as a lumped parameter based upon impact test results. This procedure of determining the hydraulic deceleration profile has been used for a recent test program and has proven very accurate.

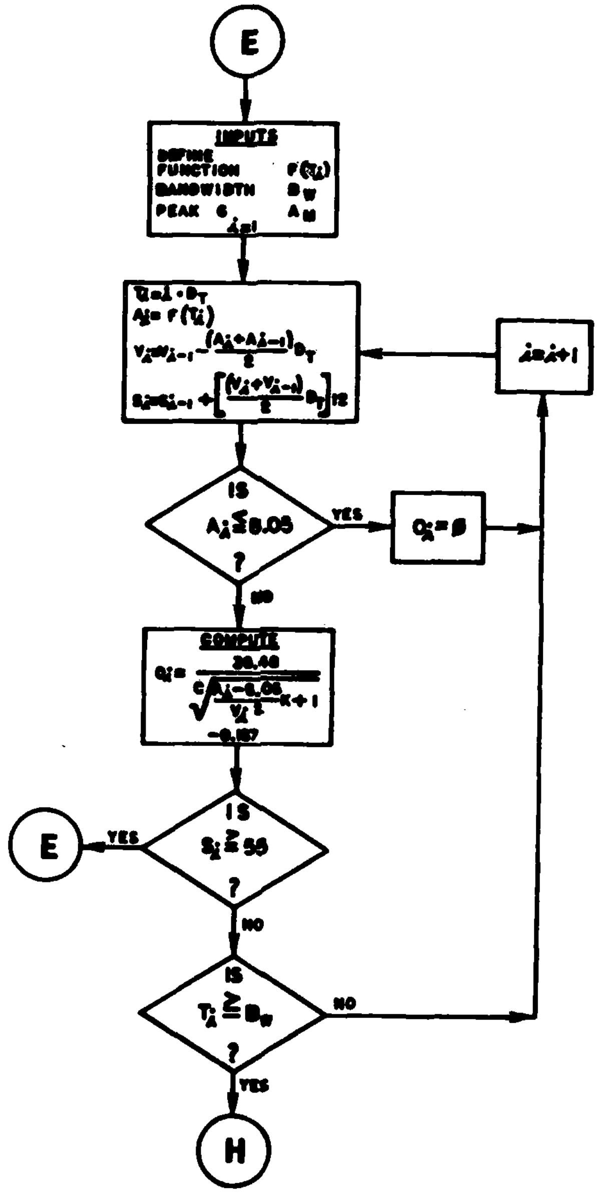
Several sources of perturbations, not covered in this report, exist which can affect the acceleration profiles obtained during impact. One is the piston striking the alignment bearing prior to entering the hydraulic deceleration device. This has occasionally produced short-duration pulses of various amplitudes at the beginning of the impact profile. The clearance between the sled glide pads and the rails allows the sled to vibrate between the rails during impact, which appears as noise on the acceleration profile. The dynamic interaction between the test subject and seat, especially during low-amplitude long-duration profiles, may also alter the pulse shape.

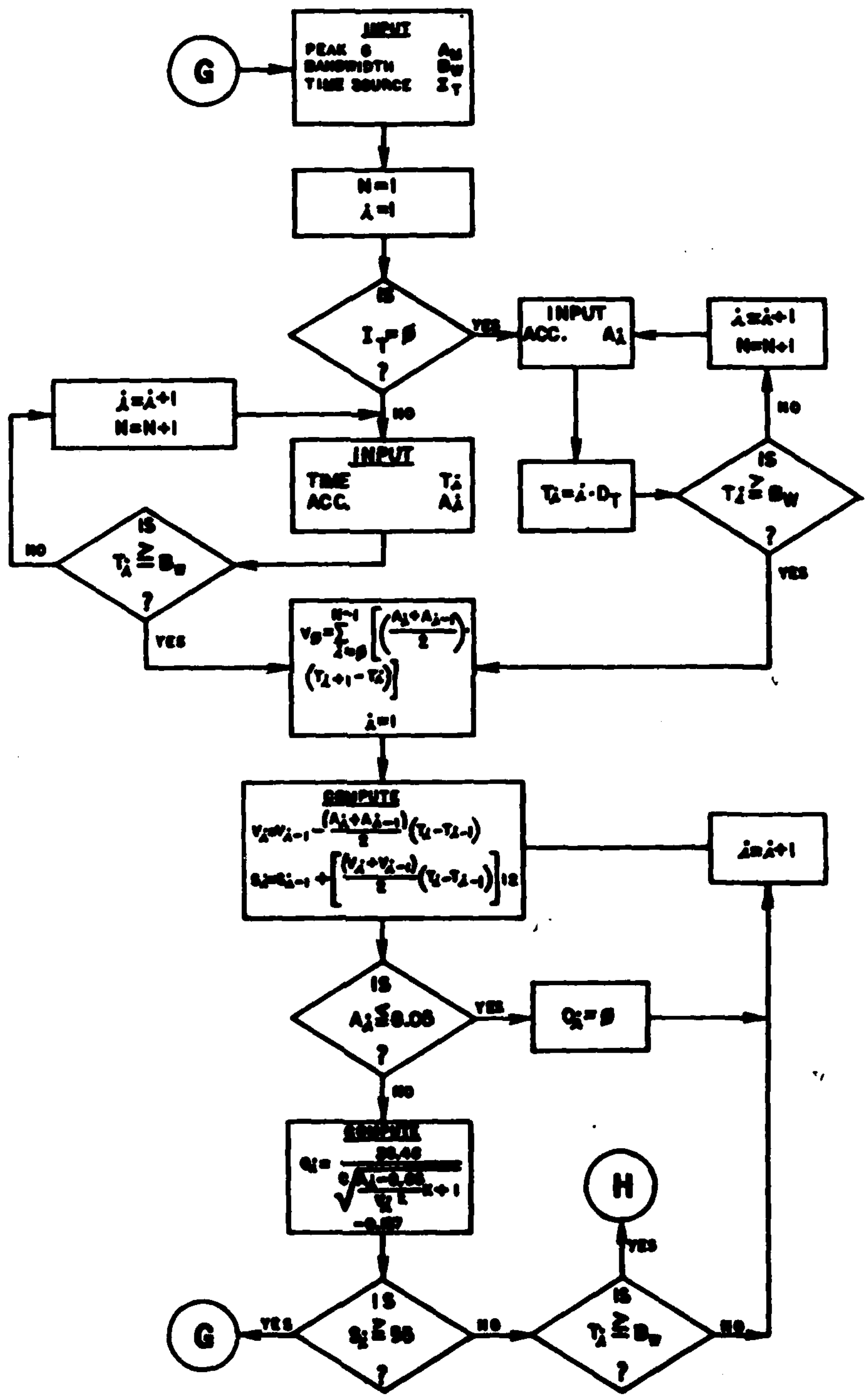


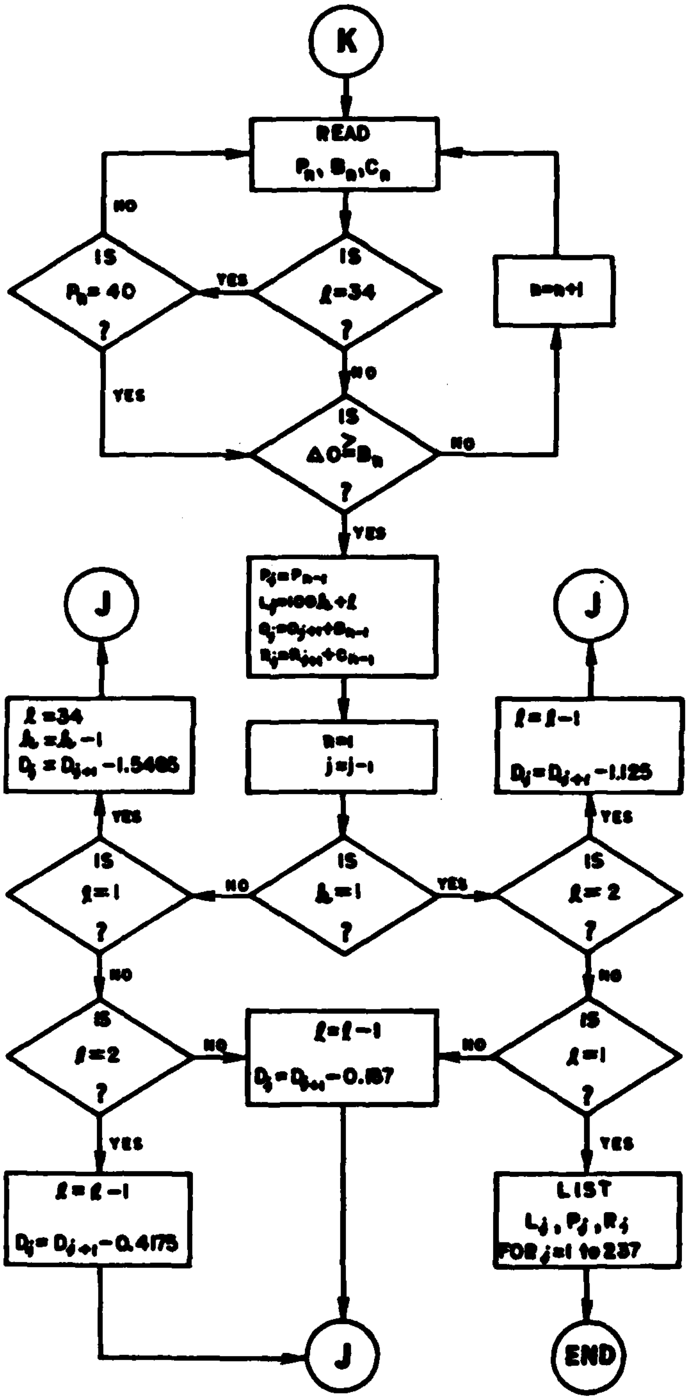
PARAMETERS

W = SLED WEIGHT (POUNDS)
P_S = PROFILE SOURCE - 1,2,3,4,5,6
D_T = DATA TIME INCREMENT (SEC)
A_M = DATA PEAK ACC. (G)
B_W = DATA PULSE WIDTH (SEC)
V_T = TOTAL VELOCITY CHANGE (FT/SEC)
S_T = TOTAL DISPLACEMENT (FT)
T_i = INSTANTANEOUS TIME (SEC)
V_i = INSTANTANEOUS VELOCITY (FT/SEC)
S_i = INSTANTANEOUS DISP. (INCH)
O_j = INSTANTANEOUS ORIFICE AREA (SQ.IN.)
A_i = INSTANTANEOUS ACC. (FT/SEC^2)
C = CORRECTION COEFFICIENT
T_R = RISE TIME (SEC.)
T_F = FALL TIME (SEC.)
I_T = TIME SOURCE 0,1
D_j = DISTANCE TO PLUG (IN)
P_n, P_j = PLUG IDENTIFICATION
B_n = PLUG ORIFICE AREA (SQ.IN.)
L_j = PLUG LOCATION
C_n = PLUG EFFECTIVE AREA (SQ.IN.)
R_j = TOTAL EFFECTIVE AREA (SQ.IN.)


C
INPUT
PEAK G
RISE TIME
BANDWIDTH
IS
?
NO
YES
COMPUTE
IS
?
YES
NO
COMPUTE
"DISPLACEMENT TOO LARGE, USE SMALLER PEAK G AND/OR BANDWIDTH."
C
H
YES
NO
NO


E
INPUTS
DEFINE
FUNCTION
BANDWIDTH
PEAK G
i=1
i=i+1
IS
YES
NO
?
COMPUTE
IS
YES
E
NO
IS
NO
YES
H


G
INPUT
PEAK G
BANDWIDTH
TIME SOURCE
N=1
IS
YES
INPUT
ACC.
NO
INPUT
TIME
ACC.
IS
NO
YES
IS
YES
COMPUTE
IS
YES
NO
COMPUTE
H
YES
G
YES
IS
NO
IS
NO



DATA

n	P_n	B_n	C_n
1	1	Ø.944	Ø.944
2	3	Ø.681	Ø.713
3	31	Ø.558	Ø.6Ø1
4	2	Ø.452	Ø.499
5	32	Ø.328	Ø.371
6	4	Ø.215	Ø.248
7	33	Ø.159	Ø.184
8	8	Ø.1Ø3	Ø.12Ø
9	34	Ø.Ø8Ø	Ø.Ø93
1Ø	16	Ø.Ø53	Ø.Ø62
11	2Ø	Ø.Ø42	Ø.Ø49
12	25	Ø.Ø35	Ø.Ø41
13	34	Ø.Ø27	Ø.Ø32
14	36	Ø.Ø17	Ø.Ø2Ø
15	37	Ø.ØØ8	Ø.Ø1Ø
16	Ø	Ø	Ø
17	41	3.976	3.976
18	43	2.726	2.853
19	42	1.8Ø8	1.996
2Ø	431	1.313	1.485
21	44	Ø.864	Ø.994
22	432	Ø.636	Ø.737
23	433	Ø.499	Ø.58Ø
24	48	Ø.411	Ø.479
25	434	Ø.332	Ø.388
26	416	Ø.212	Ø.248
27	42Ø	Ø.167	Ø.196
28	425	Ø.137	Ø.161
29	4Ø	Ø	Ø

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